TREES for Strip-Mined Lands

A report on 10-year survival and growth of trees planted on coal-stripped lands in Pennsylvania's bituminous region.

by
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William R. Byrnes

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A Problem in Planting

OPEN-PIT or strip mining has become an important method of mining bituminous coal in Pennsylvania. In 1958 some 19.5 million tons of soft coal--29 percent of the total bituminous production in the State--were produced by this method.

The land area affected by strip-mining is small. For example, Clearfield County now produces more strip-mined bituminous coal than any other county in the State, yet the area affected by stripping in 1958 was only 0.4 percent of the total area of the county.

Small as these strip-mined areas are, they make a distinctive mark upon the landscape. Much of the material turned up on banks remains adverse to natural establishment of vegetation for many years. Ground cover from naturally invading species is well under 50 percent after 10 years, and there is very little desirable tree cover after 20 years *(2)*. If these areas are to be covered with trees having possible economic value, those trees must be planted.

The Pennsylvania Department of Mines and Mineral Industries estimates that about 10,000 acres of strip-mined bituminous lands are being restored to trees and grasses each year in Pennsylvania. Some of this planting is on land strip-mined before legislative action in 1946 which required restoration of strip-mine banks. Yet most of this yearly planting job is on freshly-made banks 1 to 3 years old.

An important problem in reforesting these areas is to determine the best tree species to use. To help solve this problem, 22 research-demonstration plantings were established from 1946 to 1949 by The Pennsylvania State University School of Forestry, in 14 counties of central and western Pennsylvania (fig. 1). The test plantings, each approximately 1 acre in size, were designed to include about 100 trees of each species being tested. The individual species were planted at a 6- by 6-foot spacing in small blocks consisting of four or five rows running up and down the slope.

From 4 to 16 different tree species, totalling 400 to 1,600 seedlings, were planted in each test area. Four shrub species were planted on each of four banks. Seedlings were hand-planted with mattocks in the spring on 1- to 3-year-old strip-mine banks.

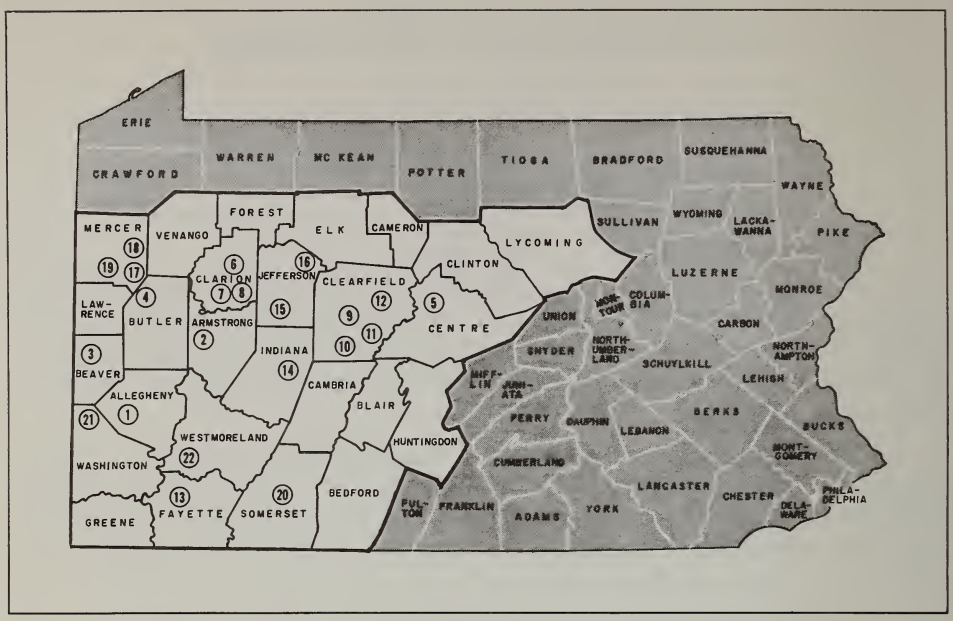

Figure 1.--*The distribution of the test plantings on strip-mine banks in the bituminous coal region of Pennsylvania. Figures indicate the number of the test planting.*

Personnel from the School of Forestry of the Pennsylvania State University measured these experimental plantings 5 years after establishment. The 5-year results have been published *(1)*.

For a more conclusive study of these plantations, a cooperative project was undertaken in 1958 by the Pennsylvania Department of Forests and Waters, the Pennsylvania Department of Mines and Mineral Industries, The Pennsylvania State University, the Izaak Walton League of Pennsylvania, the Independent Mineral Producers Association, and the Northeastern Forest Experiment Station. This is a report on that project. It presents information on survival, growth, and development of tree and shrub species after 10 growing seasons.

Conditions Studied

Total height was measured for all species; and, in addition, for those trees more than 10 years old, 10-year height was measured. In most cases, all trees present were measured; but where the trees in a block were taller than about 17 feet, every other tree in each row was measured,

giving a sample of 30 to 60 trees. A complete count was made to determine survival percent. Diameter at breast height was recorded for all trees larger than 2.0 inches. An appraisal was made of the form and vigor of each individual, and each tree was inspected for disease and insect damage. All tree data were recorded by topographic position as lower half slope, upper half slope, and ridge top.

Samples of the bank material were taken at each test area to get an estimate of certain soil characteristics in the 3- to 9-inch depth. Three samples were taken at equally spaced points along the contour within each topographic position. Samples were taken, when possible, on surface material bare of vegetation in order to determine soil characteristics of the unvegetated areas. (The study was not designed to investigate the soil characteristics under different types of vegetative cover.)

Soil content was determined by screening the samples and finding the proportion of soil particles less than 2 mm. in diameter. Soil texture was determined according to the Bouyoucos hydrometer method. Organic-matter content and the readily available nutrients--phosphorous and potassium--were also determined. About a dozen well-distributed soil samples per bank were taken for pH determination by the glass-eloctrode technique.

Because of the methods used in strip-mining operations, extreme variations in site are encountered. A summary of important soil characteristics is given in table 1.

BANK TYPES

Banks are composed of different rock material, depending on the geologic structure of the area. These materials vary in such characteristics as color, consistency, acidity, and rate of weathering. When the test plantings were established, the banks were classified into four types *(3)*. Of the 22 test plantings, 16 were made on Type II banks (table 1).

Their surface material came predominantly from soft, thick-bedded shales, yellow to brown in color, and to a lesser extent from sandstone and thin-bedded carbonaceous shales. Type II banks are moderately to strongly acid (usually pH is between 4.0 and 5.5); they have a compact consistency, and weather rather rapidly. A description of the other three bank types can be found in the Appendix.

Table 1.--Bank characteristics on test areas, 10-15 years after formation

Test No.	Location (County)	Bank type	Soil content	Soil texture				Acidity		Organic matter	Readily available nutrients	
				Particle size			Textural classification	Average	Range		P	K
				Sand	Silt	Clay						
			Percent	Percent	Percent	Percent		pH	pH	Percent	Pounds per acre	
1	Allegheny	II	68	29	36	35	clay loam	5.7	4.3-6.9	3.0	7	130
2	Armstrong	II	37	22	40	38	clay loam	4.1	3.9-4.4	1.7	3	155
3	Beaver	II	62	27	40	33	clay loam	4.7	4.5-5.7	4.0	3	95
4	Butler	II	76	14	39	47	clay	4.0	3.4-5.6	1.3	3	97
5	Centre	II	50	44	33	23	loam	3.7	3.5-4.0	3.0	0	75
6	Clarion	I	50	29	47	24	loam	3.2	2.8-3.6	2.3	2	88
7	Clarion	I	41	35	37	28	clay loam	3.3	2.9-4.6	1.9	1	104
8	Clarion	II	49	24	39	37	clay loam	4.0	3.8-4.6	3.2	0	113
9	Clearfield	II	32	36	32	32	clay loam	3.6	2.9-4.5	1.7	2	105
10	Clearfield	II	25	45	26	29	clay loam	4.1	3.6-5.0	3.0	8	157
11	Clearfield	II	37	37	31	32	clay loam	3.6	2.5-4.3	3.6	4	102
12	Clearfield	II	37	44	33	23	loam	4.0	3.7-4.5	2.6	0	112
13	Fayette	II	43	44	27	29	clay loam	3.7	3.0-4.4	4.4	0	60
14	Indiana	II	31	36	35	29	clay loam	5.0	4.2-6.0	1.6	5	82
15	Jefferson	II	48	20	42	38	clay	3.8	3.1-5.0	1.5	1	70
16	Jefferson	II	24	25	40	35	clay loam	4.5	4.2-4.7	2.2	0	68
17	Mercer	IV	67	34	28	38	clay loam	4.3	2.9-5.8	2.4	7	90
18	Mercer	IV	64	34	33	33	clay loam	5.7	3.2-7.4	1.4	16	72
19	Mercer	IV	57	68	20	12	sandy loam	6.9	5.8-7.8	1.1	17	57
20	Somerset	II	29	38	34	28	clay loam	4.5	4.2-4.9	2.8	0	91
21	Washington	II	42	40	38	22	loam	4.1	3.6-4.4	2.8	4	90
22	Westmoreland	III	68	55	21	24	clay loam	4.2	3.8-4.4	4.3	0	118

SOIL CONTENT

Among the different test banks there is a wide range in soil content (particles less than 2 mm. in diameter) after 10 to 15 years' exposure (table 1). In grouping the banks it was found that 14 of them had soil contents of 40 percent or greater:

Percent soil by weight	*Number of tests*
20 - 29	3
30 - 39	5
40 - 49	5
50 - 59	3
60 - 69	5
70 - 79	1

Bramble *(1)* has estimated that as little as 20 percent soil content is enough for adequate survival. On many banks, a zone of material having a high soil content was observed just below the surface and just above a layer of larger rocks about a foot deep. This soil was formed by the weathering of the surface shale. The shale surface has a mulch-like effect in retaining moisture.

Weathering of rock material proceeds rapidly for the first several years, then gradually slows down. Through physical deterioration and chemical decomposition, predominantly shale banks form soil much more rapidly than do sandstone banks.

SOIL TEXTURE

Soil texture affects the aeration and moisture conditions of the bank. Soils of the test banks are relatively fine-textured. Seventeen of the 22 banks were either clay loam or clay (table 1). These fine-textured soils were derived from either thin-bedded or thick-bedded blue or tan shales.

SOIL ACIDITY

Acidity, or soil reaction, is generally considered to be one of the most critical factors in strip-mine forestation. The effects of acidity upon tree survival and growth have not been investigated thoroughly, nor have the tolerances of individual species been determined precisely. The general opinion is that extremely high and low acidity--below pH 4.0 and above pH 8.0--greatly limits the physiological activity of the trees. Within the broad range from pH 4.0 to pH 8.0 acidity seldom limits tree growth.

Two banks of glacial material (tests No. 18 and 19) were notably less acid than other banks. The low acidity on test No. 1 was due to heavy applications of limestone and fertilizer before planting. Nineteen banks rated in acidity between pH 3.1 and pH 5.0:

pH range	*Relative acidity*	*Number of test areas*
3.1-4.0	Very strongly acid	10
4.1-5.0	Strongly acid	9
5.1-6.0	Mildly acid	2
6.1-7.0	Mildly acid to neutral	1

Of the 10 very strongly acid areas, two were extremely acid--pH values of 3.2 and 3.3. These banks, representative of many areas observed around Clarion, Pa., pose a real problem in reforestation. Most species planted here failed completely. Those species that best survived on the bank with acidity of pH 3.2 were red oak (29 percent), Banks pine (25 and 1 percent on two test blocks), pitch pine (23 percent), and red pine (21 percent). The other eight test areas in the very strongly acid category had soil reactions between pH 3.6 and 4.0; tree survival on these was not nearly so poor. Thus, below pH 3.3 survival was very poor, and above pH 3.6 acidity was not so strongly a limiting factor.

The question is often asked: Does acidity decrease with the passage of time? When the test plantings were established, acidity measurements were taken. On nine areas for which we have comparable acidity measurements, four decreased slightly in acidity and five increased slightly in acidity over 10 years. There was no marked decrease in acidity, at least not over the 10-year period.

ORGANIC CONTENT AND READILY AVAILABLE NUTRIENTS

Soil samples from each test bank were analyzed for organic matter and readily available nutrients by the Soil Testing Laboratory at The Pennsylvania State University.

A wide range in organic content was found, from 1.1 to 4.4 percent (table 1). Expressed in reference to nutrient levels for agricultural crops, the organic contents are considered medium to high. Much of the organic matter on strip-mined lands is believed to be residual particles of coal.

Nutrient analyses show that the strip-mine soils were generally very deficient in phosphorous (P) when compared to

agricultural standards. Potassium (K) was more abundant on the test banks than phosphorous: nine banks had medium to high levels by agricultural standards.

Survival and Growth

The primary objective of this study was to determine the survival, height, and relative vigor of each of the 16 tree species and 4 shrub species after 10 growing seasons as a guide for future plantings.

After 10 growing seasons, the survival of hardwood species was in general higher than that of the coniferous species. Black locust, red oak, green ash, and white ash had an average survival of 60 percent or better (table 2). The two species of ash exhibited the highest survival: ash plantings on most test banks fell into the "good" survival category, indicating 61 to 100 percent survival.

Table 2.--Survival on all test areas combined after 10 growing seasons, by species

Species	Average survival	Test plantings with survival--		
		Good (61 - 100%)	Adequate (41 - 60%)	Unsatisfactory (0 - 40%)
	Percent	No.	No.	No.
Hardwoods:				
Hybrid poplar	45	3	1	4
Black locust	60	9	2	6
Red oak	62	5	2	2
Green ash	69	12	1	2
White ash	65	10	1	2
Black walnut	26	0	1	5
Conifers:				
Japanese larch	42	2	7	7
Banks pine	38	5	5	13
Scotch pine	80	4	0	0
Pitch pine	36	3	4	11
Red pine	49	3	2	3
European larch	34	0	1	2
White pine	39	4	3	9
Douglas-fir	24	1	3	6
White spruce	29	0	2	4
Ponderosa pine	16	0	0	7
Shrubs:				
Arrowwood	47	2	0	2
Hazelnut	30	0	2	2
Silky dogwood	45	2	1	1
Black chokeberry	66	3	0	1

Table 3.--Height and diameter on all test areas combined after 10 growing seasons, by species

Species	Test areas	Height		Diameter at breast height (d.b.h.)	
		Bank average	Bank range	Trees over 2.0 inches d.b.h.	Average diameter of trees over 2.0 inches d.b.h.
	No.	Feet	Feet	Percent	Inches
Hardwoods:					
Hybrid poplar	8	30.8	23-36	90	5.4
Black locust	17	23.3	20-32	98	4.1
Red oak	9	8.6	6-14	13	2.7
Green ash	15	7.5	2-11	3	--
White ash	13	6.9	2-10	2	--
Black walnut	7	3.9	2- 6	0	--
Conifers:					
Japanese larch	16	15.4	9-24	58	3.6
Banks pine	23*	10.4	2-16	50	2.8
Scotch pine	4	8.4	7-10	13	2.2
Pitch pine	18*	8.2	5-11	44	2.8
Red pine	8	7.0	5-11	30	2.5
European larch	3	6.4	3-10	5	--
White pine	16	5.0	3- 8	8	--
Douglas-fir	10	4.0	2- 7	0	--
White spruce	6	3.9	2- 5	0	--
Ponderosa pine	7	3.9	3- 6	0	--
Shrubs:					
Arrowwood	4	4.0	--	0	--
Hazelnut	4	3.7	--	0	--
Silky dogwood	4	3.4	--	0	--
Black chokeberry	4	3.0	--	0	--

*Duplicate plantings made on several test areas.

For the conifers, with the exception of Scotch pine, the average survival was less than 50 percent. The large number of plantings with unsatisfactory survival of Banks and pitch pine is believed due partly to early mortality from sawfly injury.

Black locust, red oak, green ash, white ash, Japanese larch, Scotch pine, and red pine had more test plantings in the "good" and "adequate" survival categories than in the "poor" category.

In table 3 the species are listed in descending order according to their height at 10 years. Hybrid poplar and black locust were outstanding among the hardwoods; Japanese larch and Banks pine exceeded other conifers.

There was little change in this relative height standing from 5 years to 10 years. Red oak and Scotch pine were two exceptions. Red oak has surpassed both species of

ash during the past 5 years, while Scotch pine pulled ahead of European larch, red pine, and pitch pine.

Three hardwood species and five conifer species attained an annual height growth of 1 foot or more during the second 5-year period: hybrid poplar (4.1 feet per year), black locust (2.3 feet), red oak (1.2 feet), Japanese larch (2.0 feet), Banks pine (1.4 feet), Scotch pine (1.3 feet), pitch pine (1.1 feet), and red pine (1.0 foot). Figure 2 shows average height and survival after 10 growing seasons for all tree species.

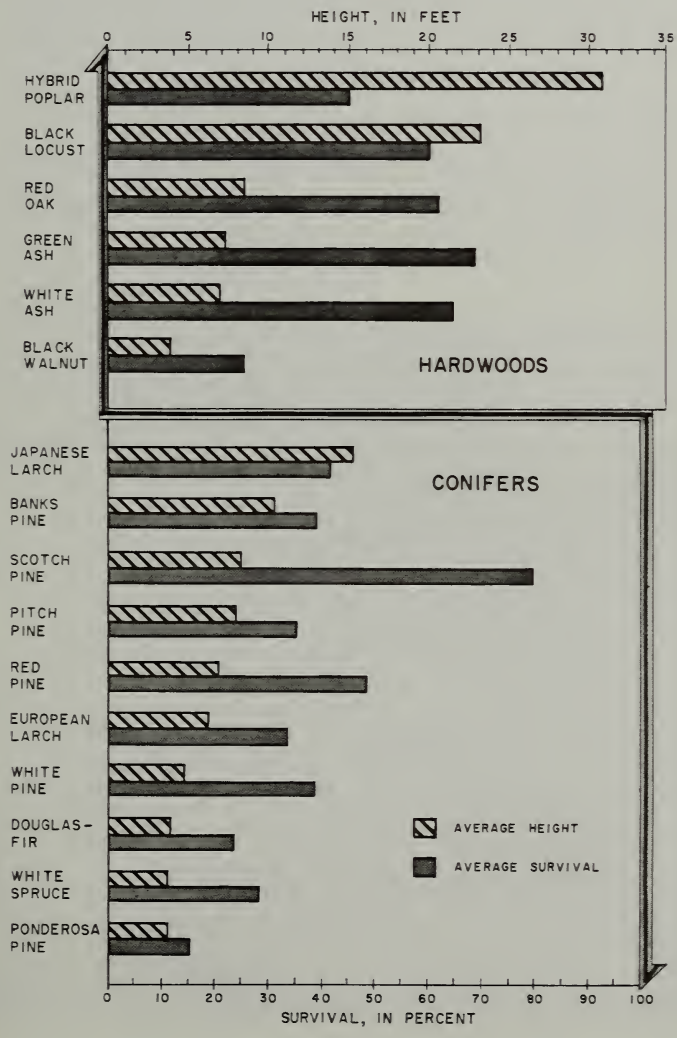

Figure 2.--*The average height and average survival of the tree species tested, after 10 growing seasons.*

On the basis of survival and height measurements and from observations of vigor and form, each species can be placed into one of three categories: (1) good development, (2) fair development, or (3) poor development.

TREES RATED GOOD

Hybrid Poplar

In regard to rapid growth, there is no question that hybrid poplar is the outstanding species tested (fig. 3). Its average height at 10 years was just under 31 feet, and the stems averaged 5.4 inches d.b.h. The largest tree measured, a 12-year-old, was 56 feet tall and 10.5 inches d.b.h.

Poplar trees are often susceptible to a canker that causes the stem to break apart. This condition was found on 10 to 40 percent of the trees on any one test, but usually only one or two very small cankers were found on a tree (fig. 4). There were no indications that stem breakage due to canker would occur in the near future.

Figure 3.--*Hybrid poplar was outstanding among the trees tested. At 11 years these hybrid poplars averaged 42 feet in height. Somerset County.*

The hybrid poplar was established by using cuttings, and it appears that adequate survival (over 40 percent) can often be obtained by this method. On the four test areas where survival was unsatisfactory (table 2), an access road on one test area destroyed many poplars while on another test area extremely high acidity may have been responsible

Figure 4.--*Stem cankers like this were found on some of the hybrid poplars, but they have not caused damage to the plantings.*

for the mortality. Hybrid poplars were planted on parts of banks believed to have a high soil content--the rounded ends, or banks produced by the first stripping cut. This practice probably resulted in higher survival and better growth than if they had been planted on the more rocky ridge tops.

The form of the hybrid poplar was excellent--very few trees had double stems. Although the litter and plant vegetation developing under this species was very sparse, the dense, closed canopy provided some degree of erosion control by protecting the soil surface from the impact of heavy rains.

Dr. Ernst J. Schreiner, geneticist for the Northeastern Forest Experiment Station, examined rooted cuttings of these poplars and visited two test plantings. According to him, this hybrid is a male clone--the parentage being either *Populus maximowiczii x Populus trichocarpa* or *P. maximowiczii x P. 'Berolinensis'*.

Because of its ability to survive and grow on extremely adverse sites, black locust has been used widely for reforestation of degraded lands and strip-mines. The 10-year measurements (tables 2 and 3) indicated that the locust was continuing to grow well on most test areas (fig. 5), though on a few there was evidence of declining vigor and increasing borer activity (fig. 6).

The form of the locust was fair to poor. Between one-half and three-quarters of the trees on any one test area had multiple stems, branching out close to the ground (fig. 5). Only very short, small post material could be cut from these locust trees at this time.

Figure 5.--*Black locust grew well on most test areas. This planting in Clearfield County has an excellent ground cover of bluegrass. Notice the large number of multiple stems.*

Figure 6.--*Locust with severe borer damage. Generally the locust trees have good to excellent vigor, and are not breaking up because of borer activity.*

Figure 7.--*Red oak has grown very well on the mine banks. This stand on a clay bank with high soil content, in Butler County, was 14 feet tall at 12 years.*

The greatest value of black locust apparently lies in its effect on the soil, rather than in its commercial usefulness. Chapman and Lane *(4)*, discussing the effects of locust on the height growth of interplanted hardwoods in old fields in the Central States, declared that "...if locust has no other value than to improve the site and stimulate the growth of associated hardwoods, the cost of its planting is fully justified."

On bituminous strip-mined lands in Pennsylvania, black locust, after 10 growing seasons, has formed a dense, protective canopy. Litter 1 to 2 inches deep covered the surface under locust blocks on all plantings. A luxuriant growth of herbs and grasses (blackberry, pokeweed, thistles, elderberry, timothy, and bluegrass) was invariably present. Naturally established seedlings of hickory, maple, oak, and cherry were commonly found under locust. Because of its consistently good survival and growth, together with the excellent ground cover and soil improvement it brings about, black locust is recommended particularly on steeper slopes and on banks that have low soil content.

Red Oak

This species has been used in many commercial plantings on strip-mines in Pennsylvania. Its high survival and good height growth appear to justify continued use (fig. 7). Average survival was 62 percent (table 2). The two plantings with unsatisfactory survival had soil acidities of pH 3.2 and 3.7. There was almost no litter or ground vegetation present under red oak plantings.

A comparison of the height and survival of this species on banks with fine-textured and coarse-textured soils was made. On six banks with an average silt plus clay content of 77 percent, the 10-year height of red oak was 10.9 feet and survival was 68 percent. On six banks with relatively coarse-textured soils (51 percent silt plus clay), the red oak was 7.4 feet in height with 57 percent survival. This indicates that soil texture may have an effect upon growth and survival of this species. Studies in the Central States indicate that growth and survival of most species are usually better on fine-textured soils *(5)*.

Height data for red oak were examined to see if better growth was obtained on the lower slopes than on the upper slopes. On six plantings with distinct slope positions the trees on the lower slope averaged 11.2 feet in total height while those on the upper portion averaged only 8.8 feet. Because of this good growth and survival on better sites within a strip-mine bank, red oak is recommended for plantings on the lower slopes and sheltered coves. These parts of the bank frequently have a higher soil content and better moisture relations.

Japanese Larch

This species has done very well on many of the test plantings (fig. 8); and, after 10 years, it is the tallest species among the conifers tested (table 3). Over one-half the stems are more than 2.0 inches d.b.h., and of these the average diameter is 3.6 inches. This indicates that many of these larch plantings are approaching the size at which some trees can be utilized for small products--posts or cordwood. The average survival was 42 percent (table 2), adequate but considerably lower than that of most hardwoods. Seven test areas had unsatisfactory survival. With Japanese larch, low survival was partially offset by the large size the trees attained and the rapid development and closure of the crown. On several areas with unsatisfactory survival, larch seemed to be fully occupying the planting area.

Japanese larch was exceptionally vigorous and appeared to be entirely free from insects and diseases. A uniform layer of litter, $\frac{1}{2}$ to 1 inch thick, was found under most plantings. This augments the cover value of this species.

Striking differences were observed in the growth response of Japanese larch on graded and ungraded banks. ("Graded" banks are coal strippings that have been worked over with bulldozers to approximately the original contours of the land.) On six graded banks the height at 10 years averaged 12.3 feet while on six ungraded banks the average

Figure 8.--*Japanese larch has performed very well. This planting is 25 feet tall at 12 years.*

was 20.8 feet. Though this difference may not be attributed to grading alone, there appears to be some differential performance by this species on graded and ungraded banks.

A comparison of height growth by slope position indicates that Japanese larch made about equal growth on upper and lower slopes alike. This would indicate that satisfactory plantings of this species can be made on portions of banks which are not suitable for other species.

With larch, particular care should be used to obtain good planting stock and to handle it properly. Several test areas had to be replanted. Failure was attributed to the seedlings breaking winter dormancy before they were planted.

Because of the excellent growth, the fair cover value of the litter, and the possibility for utilization, it is strongly recommended that increased use be made of Japanese larch for strip-mine plantings in this region.

Banks Pine

Banks pine, commonly called jack pine, has been widely used for strip-mine planting in the Central States and in Pennsylvania. On these test plantings its growth and survival were extremely variable. Average heights ranged from 2 to 16 feet (table 3). Average survival was from 0 to 84 percent.

Banks pine has the capacity for excellent growth on mine strippings (fig. 9). Unfortunately, this capacity is

Figure 9.--*Banks pine also grew well on coal-stripped lands. These pines were 14 feet tall at 12 years.*

seldom expressed because defoliation by the pine sawfly either reduces the vigor or kills the young trees. Thirteen test areas had survival below 40 percent, and mortality on five test areas can be attributed entirely to sawfly defoliation. Excluding tests with this defoliation mortality brings the overall survival up from 38 to 44 percent. Unless control measures are contemplated, Banks pine should not be planted in localities known to have high populations of this insect.

Banks pine provides relatively good cover for the soil surface with an abundant layer of pinestraw 1 to 2 inches deep. And it has very dense crowns. The year-around green foliage of this and other pines gives a pleasant appearance to the landscape--an important aesthetic by-product of strip-mine reforestation.

Invariably, heavy crops of cones were observed on Banks pine. On 10 test areas, seedlings of this species had become established naturally. Most were just 1 year old; but on a few areas 2- and 3-year seedlings were found (fig. 10).

Figure 10.--*Banks pine has produced natural seedlings on 10 test areas. Parents of this seedling are 12 years old.*

Scotch Pine

This species was test-planted on only four banks but appears to be a very promising tree. The range in heights from 7 to 10 feet (table 3) indicates that its performance was reliable on several areas. The overall survival of 80 percent was the best survival among the conifers. Both vigor and form of Scotch pine were good, although on one area many stems were deformed by insect damage, possibly by the European pine shoot moth.

After 10 growing seasons Scotch pine was still open-grown on these test areas. Because the canopy had not closed, little protection was given to the soil surface and needle litter was not nearly so abundant as under Banks and pitch pine.

Further evaluation should be made before extensive use is made of Scotch pine in large-scale plantings on strip-mine lands. This species could well have a prominent role in strip-mine forestation.

TREES RATED FAIR

The species discussed in this section--green ash, white ash, pitch pine, red pine, and white pine--are not considered as well-suited for strip-mine plantings as those six species discussed above because of one or more unfavorable characteristics. These species could be regarded as

border-line cases in strip-mine forestation--sometimes they do well and at other times they perform poorly.

Green ash.--In spite of good survival, green ash has been rather disappointing in the 10-year measurements. Its average height growth has fallen well behind that of several other hardwoods. The less vigorous trees of this species were found to have moderate to heavy infestations of oyster-shell scale. Leaf aphids were observed in varying intensities. Serious damage by recent attacks of the 17-year cicada *(Magicicada septendecim (L.))* was done to green and white ash in Centre and Clearfield Counties (fig. 11).

The form of green ash was variable. There was strong

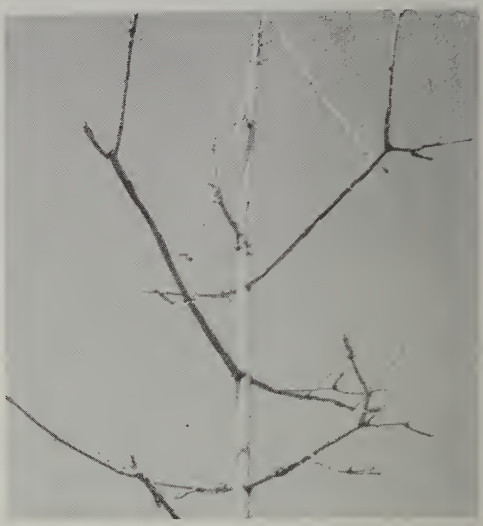

Figure 11.--*Attacks by the 17-year cicada have damaged ash plantings in Centre and Clearfield Counties.*

Figure 12.--*Green ash planted on steep slopes had a tendency to produce double stems. Note the 'pistol butt' form.*

Figure 13.--*An abundant set of seed on a green ash 11 years old in Somerset County.*

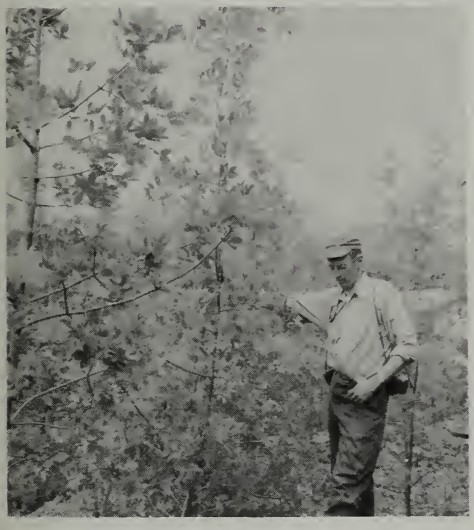

Figure 14.--*A vigorous stand of white ash in Somerset County, 12 feet tall at 10 years.*

tendency for these trees to develop double stems, particularly when planted on steep slopes (fig. 12). This species provides very little protection to the surface; litter deposition is minimal. It is interesting to note that, on seven test areas, seeds were present on several of the larger green ash (fig. 13); however, no naturally established seedlings were found.

The principal reason for rating green ash as fair was its generally poor height growth and its very low cover value. This species did better on lower slopes than on the upper slopes and tops. On five ungraded banks the average heights were 11.5, 8.4, and 7.6 feet on the lower half slope, upper half slope, and ridge top, respectively.

White ash.--The appraisal for white ash is about the same as that for green ash. Extreme variations in height and vigor seemed to be the rule with both species (fig. 14). Since other hardwood species are capable of much better performance, white and green ash are not highly recommended. If these species are to be planted, they should be restricted to the superior sites on a bank.

Pitch pine.--This conifer has not been satisfactory in the test plantings. Survival was low--the average, 36 percent. As in the case of Banks pine, the pine sawfly accounted for much of the mortality of pitch pine. The performance of this species on an extremely acid bank was good enough to indicate that pitch pine can tolerate high acidity.

One feature that does not commend pitch pine for strip-mine planting is its form. On several of the tests, 10 to 20 percent of the trees were stunted, prostrate, or extremely bushy. This appears to be characteristic of pitch pine when planted on areas severely exposed to wind. Origin of the planting stock is also believed to be partially responsible for the poor form of pitch pine.

Abundant pine litter was observed in the area directly under the crown. Canopies had not closed completely on any test plantings. About one-half of the trees measured had mature cones, and naturally established 1- and 2-year seedlings were found on three areas.

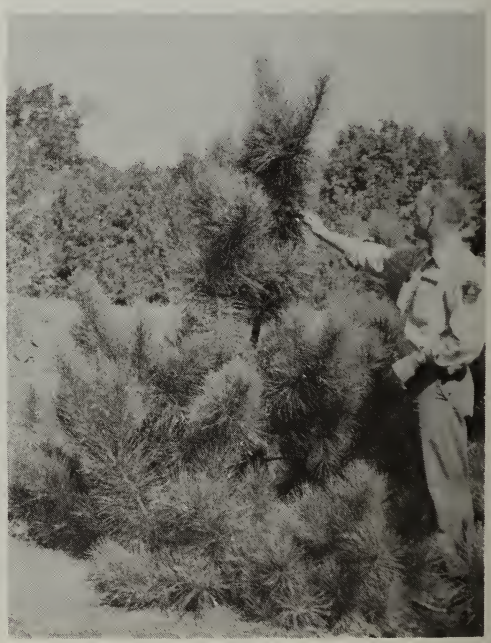

Figure 15.--*A red pine deformed by pine shoot moth, in a planting in Clarion County. Note the bushy appearance and the lack of a dominant leader.*

Figure 16.--*Where not attacked by the pine shoot moth, red pine survived well and grew well. This stand in Beaver County averaged 11 feet tall at 10 years.*

Red pine.--Red pine is not recommended for strip-mine plantings in areas of Pennsylvania that have a high incidence of pine shoot moth. This insect destroys the terminal and lateral buds, causing dense tufts of needles to form. Stunted, bushy trees often are the result of pine shoot moth injury (fig. 15).

Survival of red pine was high for conifers--almost 50 percent. When not molested by the pine shoot moth, excellent growth and form can be achieved by this species (fig. 16). Litter accumulation and soil surface protection were fair for this species. Crown closure had not occurred on many test plantings at 10 years.

Success of red pine depends to a great extent upon the incidence of pine shoot moth. Local experience with this species and with the pine shoot moth should guide planters in deciding whether or not to use this species in strip-mine forestation.

White pine.--After 10 years, this species averaged between 3 and 8 feet in height on these test plantings, with an average survival of 39 percent. For white pine, this is poor growth. Eleven of the 16 test plantings had serious white-pine weevil infestation. On these tests, about 40 percent of the trees had the top foot or two of the leader damaged or killed by the white-pine weevil. On exposed ridge tops white pine was much less vigorous than other pines (fig. 17). If this species is to be planted, it should be restricted to sheltered areas and lower slopes of banks in localities with a low incidence of white-pine weevil.

Figure 17.--*White pine performed poorly. On this exposed bank top in Centre County the white pine (center row) showed low vigor. Compare the white pine with the vigorous Scotch pine in the outer rows.*

TREES RATED POOR

The five species in this category: European larch, Douglas-fir, ponderosa pine, white spruce, and black walnut did not have survival and growth sufficient to justify their use in strip-mine plantings in this region.

European larch.--Both form and vigor of this species were considered poor to very poor on all three test plantings. At least one-half of the trees were prostrate and had no dominant leader developing (fig. 18).

Figure 18.--*In both form and vigor, European larch made a poor showing. Note lack of leader. Mercer County.*

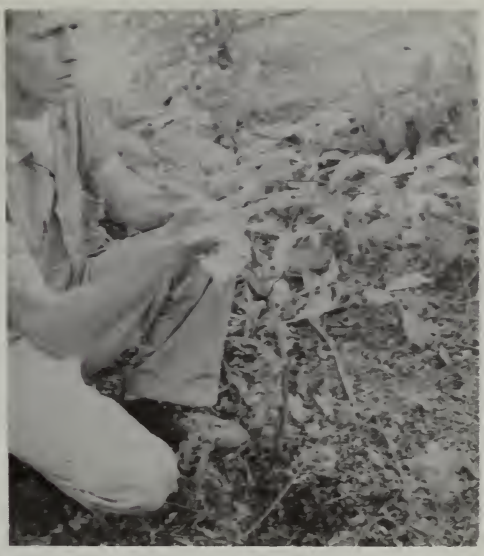

Figure 19.--*Black walnut, tried in mixtures with black locust, was badly suppressed.*

Douglas-fir.--Growth rate, survival, and cover value were too low to warrant use of this species.

White spruce.--Growth and survival were poor on nearly all of the test plantings that included white spruce. Cover value is extremely low.

Ponderosa pine.--A dry-site species in the western United States, ponderosa pine had unsatisfactory survival and poor height growth on all seven test plantings.

Black walnut.--All seven test plantings that included black walnut were alternate-row mixtures with black locust. The survival, which was unsatisfactory in all but one test, and the poor height growth demonstrate the effect of severe suppression by the locust (fig. 19).

These tests clearly showed that the growth of black walnut was extremely poor in an alternate-row mixture of walnut and locust when no attempt was made to favor the walnut by removing part of the locust.

SHRUB PLANTINGS

Four species of shrubs capable of producing wildlife food and cover were planted on four test areas. At 10 years, the heights of these shrubs averaged between 3 and 4 feet (table 3), which is about normal development for these species.

Figure 20.--*Among the shrubs, the black chokeberry survived very well. This one displays a medium to heavy yield of fruit. Fayette County.*

Black chokeberry survived very well (fig. 20); arrow-wood and silky dogwood both had good survival except on the one extremely acid bank where they failed completely; hazelnut survival was only fair to poor. Fruit production on arrow-wood was estimated as medium to heavy; on silky dogwood fruiting was medium; and on black chokeberry it was considered light to medium at the time of evaluation. Hazelnut usually had a few nuts on each bush.

There were indications that strip-mined lands are heavily used by rabbit, woodchuck, small birds, and deer. Small patches of wildlife shrubs on the bank itself or in strips on the toe of the bank adjacent to fields would pro-

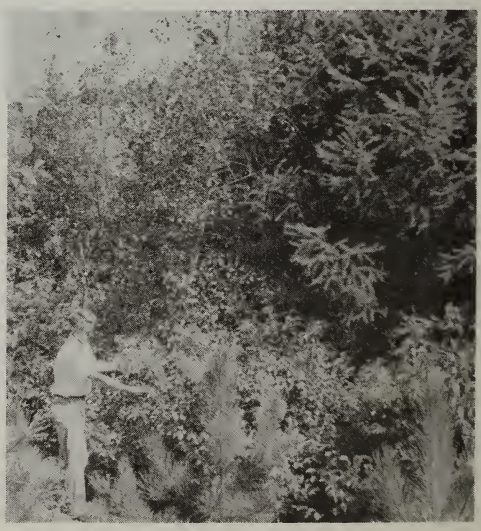

Figure 21.--*This two-row planting of shrubs provides food and cover for small game. Note Japanese larch in background. Jefferson County.*

vide a ready source of food and cover for small game (fig. 21). Such a mixture would be feasible in a constructive planting program.

MIXED TREE PLANTINGS

Black locust often serves to stimulate the growth of other interplanted hardwoods in open-field plantings *(4)*. A similar effect on strip-mine plantings has been reported by Limstrom *(5)* for hardwoods in mixture with locust, which became very decadent. He presented data showing that, after 12 years, most hardwoods planted under the decadent locust were two to three times taller than the same species planted on old fields without locust.

But on the Pennsylvania test areas, where the locust has maintained its vigor, such a mixture may not produce the same results. As Limstrom says:

> The chief difficulty stems from the fact that black locust often grows much faster on strip-mined land than it does on old fields, so that it soon overtops the associated species. Therefore competition between black locust and associated species for light and moisture in mixed stands may become critical at a much earlier age on strip-mined land than on some old fields.

Two test plantings gave some indication of the response of ash when planted with locust. In an alternate-row, simultaneous planting of equal numbers of ash and locust, the ash on the borders of the block occasionally were not overtopped. These individuals provided an estimate of the response of ash that were able to utilize the improved soil but were free from crown interference. At 11 years, the ash that were free to grow were 11 and 14 feet tall (table 4). Completely overtopped ash were about 4 feet tall. The aver-

Table 4.--Height of green and white ash after 11 years when planted in mixtures with black locust and Banks pine

Item	Height of green and white ash		
	Completely overtopped	Partially overtopped	Free to grow
	Feet	Feet	Feet
Green ash-black locust mixture	3.9	--	14.0
White ash-Banks pine-black locust mixture	4.5	6.7	11.1

Figure 22.--*In mixed plantings of ash and locust, ash did well where it was free to grow. But this ash, leaning away from the locust crown, was badly suppressed, and of poor form. Beaver County.*

Figure 23.--*In this mixed planting, in Butler County, the locust limbs have whipped the Japanese larch, killing its terminal.*

age height of ash on all test areas combined was about 7 feet.

Ash, when mixed with locust and free to grow, appeared to attain about twice the height as when it was planted without locust. But only about 10 percent of the ash were able to break through the locust canopy, and these were poorly formed and badly bent (fig. 22).

There were no test plantings of a locust-conifer mixture, but observations indicated that such a mixture would not be feasible. Conifers are much less able to compete with the locust than are the ash. For example, a row of Scotch pine planted next to locust averaged only 5.5 feet in height and had about 35 percent dead trees. Other rows farther away

averaged 8.8 feet and contained only about 5 percent dead pines. Locust exerts a detrimental effect on nearby conifers by whipping the tender terminals and by severe shading (fig. 23).

It is too soon to evaluate the mixed locust-ash plantings finally. At present this mixture cannot be recommended as a means of improving the growth of ash on these strip-mine banks. The locust 10 to 12 years after planting were not showing signs of decadence; most interplanted ash were shaded and surpressed. Because they have been supressed so long, it is questionable that the ash would now respond favorably to release. Then too, the death or cutting of the locust might produce a vigorous thicket of locust sprouts that would compete with the ash.

Our test plantings did not include mixtures in which the locust component was reduced to, say, 25 percent of the total number of trees in the block. Nor did any of these tests consist of underplanting ash after the locust became established. These techniques have been successful in the Central States *(5)*.

Until the uncertainties of mixed locust plantings on Pennsylvania strip-mine banks are resolved, black locust should be regarded as a species that improves the site for natural invasion of hardwoods rather than as a nurse species for interplanted hardwoods.

Relationships
between Bank Characteristics and Tree Survival and Growth

An outstanding feature of this study is the great variation in tree survival and growth from one strip-mine bank to another. Tables 5 and 6 in the Appendix show this variation among test areas.

Why do these differences exist? Tree response on strip-mines is an extremely complex phenomena, influenced by many factors and interrelationships. Although this study was not designed to determine the relationships between the many possible factors and tree response, it appears that certain bank characteristics--soil content, slope position, and acidity--have some discernible influence on tree survival and growth.

SOIL CONTENT

Soil content probably has an effect upon survival and growth. A wide range in soil contents, from 24 to 76 percent, was found on these test plantings. The mine banks fall conveniently into three soil-content categories: (1) low, 20 to 40 percent; (2) medium, 41 to 60 percent; and (3) high, 61 to 80 percent.

Survival and height data for each bank, by species, have been grouped into one of these soil-content categories (table 7). Red oak, green and white ash, pitch pine, and white pine had higher survival and height on banks with high soil content than on those with low soil content. Red pine and Banks pine had taller trees on banks with high soil content. On the other hand, Japanese larch and black locust did not exhibit better growth on banks with high amounts of soil.

Though these differences for some species are not very large and could be due partly to factors other than soil content, there is a rough trend for better survival and growth on strip mines with high soil content than with low soil content. Important exceptions to this trend are black locust and Japanese larch.

SLOPE POSITION

The growth of different species on various slope positions indicates a somewhat similar trend to that observed with soil content. As shown in table 8, almost all the species made better height growth on the lower half slope than on the ridge top. The notable exceptions were Japanese larch, black locust, and hybrid poplar. It is reasonable to believe that lower slopes would have higher soil contents because soil particles washed down would accumulate there. This partly accounts for the tie-in with soil-content relationships. Also, it is likely that the better growth on lower slopes is due in part to the beneficial effects of a more sheltered climate.

ACIDITY

As mentioned previously, the adverse effects of acidity upon survival appeared at or below a pH of about 3.3. The survival and height of different species on banks with acidities of pH 3.2 and 3.3 (tests No. 6 and 7) are given in tables 5 and 6. Pitch pine, red pine, and Banks pine were the only conifers that survived at all well; red oak was the sole hardwood survivor. The 10-year height growth of pitch

pine, Banks pine, and red oak on those extremely acid banks was greater than the average height of these species for all banks combined. This could indicate that the principal effects of high acidity are upon tree survival rather than growth.

Summary

During the summer of 1958, survival and growth of tree and shrub species were determined on 22 research plantings on strip-mined lands in the bituminous region of Pennsylvania. These experimental plantings were established during the period 1946 to 1949 to determine the species that are best adapted to these adverse sites.

Hybrid poplar, black locust, red oak, Japanese larch, and Banks pine exhibited the best survival and growth. Scotch pine has performed very well, but it has not been widely tested. Red oak has performed well but should be restricted to the lower slopes and protected coves within a bank. Banks pine should not be planted in localities where the pine sawfly is active, unless control measures are planned.

Green ash, white ash, pitch pine, red pine, and white pine were more variable and do not appear well suited for planting on strip-mined lands. The pines are susceptible to damage by certain insects and should not be planted in localities with high incidence of these pests. Both green and white ash have been severely infested with oystershell scale, which materially reduces their vigor.

European larch, Douglas-fir, white spruce, Ponderosa pine, and black walnut have shown poor growth and survival on these test plantings and are not recommended for strip-mine planting.

Good survival and normal development of chokeberry, arrow-wood, silky dogwood, and hazelnut in these tests indicate that successful plantings of these shrubs can be made on strip-mine banks. Patches or strips of these species provide food and cover for small game and aid in holding the soil.

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Appendix

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STRIP-MINE BANK TYPES

Bank type I.--The surface layer is composed predominantly of materials from thin-bedded carbonaceous (slaty) shales with high pyrite content, uniform dark gray color, very strongly acid (pH 2.5 to 3.5), very loose consistency, and slow rate of weathering.

Bank type II.--The surface layer is composed predominantly of materials from soft, thick-bedded shales, commonly associated with lesser amounts of sandstone and thin-bedded carbonaceous shales that do not have a high pyrite content. The surface material has a yellow to brown color, strong to moderately acid (usually pH 4.0 to 5.5 with scattered strongly acid spots as low as pH 2.5), compact consistency, and fairly rapid rate of weathering.

Bank type III.--The surface layer is composed mainly of sand and sandstone fragments with lesser amounts of shale, light yellow to rusty brown color, strongly acid (pH 4.0), loose consistency, and slow rate of weathering.

Bank type IV.--The surface layer is composed predominantly of glacial till, pale yellow in color, moderately acid (pH 4.5 to 5.0) to alkaline (pH 8), very loose consistency when moist; becomes hard on surface when dry. Considerable fine material present at time of stripping.

SCIENTIFIC NAMES USED IN THIS REPORT

Hardwoods

Hybrid poplar	*Populus maximowiczii x P. trichocarpa or P. maximowiczii x P. 'Berolinensis'*
Black locust	*Robinia pseudoacacia*
Red oak	*Quercus rubra*
Green ash	*Fraxinus pennsylvanica*
White ash	*F. americana*
Black walnut	*Juglans nigra*

Conifers

Japanese larch	*Larix japonica*
Banks pine	*Pinus banksiana*

Scotch pine ..... *P. sylvestris*
Pitch pine ..... *P. rigida*
Red pine ..... *P. resinosa*
White pine ..... *P. strobus*
European larch ..... *Larix decidua*
Douglas-fir ..... *Pseudotsuga menziesii*
White spruce ..... *Picea glauca*
Ponderosa pine ..... *Pinus ponderosa*

Shrubs

Black chokeberry ... *Pyrus melanocarpa*
Arrow-wood ..... *Viburnum dentatum*
Silky dogwood ..... *Cornus obliqua*
Hazelnut ..... *Corylus americana*

Herbs and Grasses

Pokeberry ..... *Phytolacca americana*
Thistle ..... *Cirsium vulgare*
Elderberry ..... *Sambucus pubens*
Blackberry ..... *Rubus spp.*
Timothy ..... *Phleum pratense*
Bluegrass ..... *Poa spp.*

Scientific names for tree species are from Little, Elbert L., Jr., Check list of native and naturalized trees of the United States (including Alaska); U. S. Dept. Agr. Handbook 41, 1953, except for *Larix japonica* and hybrid poplar. Scientific names for shrubs, herbs, and grasses are from Gray's Manual of Botany, 8th edition.

Table 5.--Survival and height of hardwood species on test areas after 10 growing seasons

Test No.	Hybrid poplar		Black locust		Red oak		Green ash		White ash		Black walnut	
	Survival	Height	Survival	Height	Survival	Height	Survival	Height	Survival	Height	Survival	Height
	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet
1	--	--	25	22.5	93	12.0	82	8.6	91	9.1	--	--
2	77	--*	25	26.1	--	--	91	3.7	80	--*	18	2.2
3	--	--	83	28.3	--	--	81	6.8	78**	5.8	--	--
4	--	--	93	22.1	79	10.5	63**	5.5	74	6.4	--	--
5	--	--	73	20.2	--	--	57	2.6	62	6.1	--	--
6	0	--	5	8.3	29	13.8	4	5.6	0	--	0	--
7	--	--	--	--	--	--	--	--	--	--	--	--
8	14	33.2	--	--	--	--	--	--	--	--	--	--
9	21	30.0	--	--	51	9.4	--	--	--	--	--	--
10	--	--	94	21.4	--	--	61	10.9	++	--	--	--
11	--	--	84	26.8	--	--	91	7.8	91	4.5	--	--
12	79	27.8	46	23.4	++	--	82	6.2	++	--	--	--
13	+	--	90	23.8	32	6.9	--	--	12+	5.0	30	5.7
14	90	35.8	20	22.2	--	--	74	7.2	73	7.3	40	3.7
15	20	23.0	86	23.1	73	9.3	83	7.7	72	9.1	35	3.8
16	--	--	85	22.1	55	9.0	--	--	--	--	15	4.2
17	--	--	28	21.4	--	--	***	7.5	--	--	--	--
18	--	--	86	24.1	--	--	***	8.8	--	--	--	--
19	--	--	24	31.7	62	5.9	78	11.8	68	8.8	--	--
20	44	33.2	60	20.7	--	--	77	9.8	55	10.1	45	3.5
21	--	--	24	27.2	41	6.3	84	7.9	80	6.1	--	--
22	--	--	--	--	100	8.5	--	--	--	--	--	--

*Trees cut before 10-year measurement.

**Alternate-row mixture with black locust.

***No survival count taken because exact boundary of planting could not be relocated. 5-year survival for green ash on No. 17 and No. 18 was 29 and 90 percent respectively.

+Levelled after planting.

++Planting destroyed by re-stripping.

Table 6.--Survival and height of coniferous species on test areas after 10 growing seasons

Test No.	Japanese larch		Banks pine		Scotch pine		Pitch pine		Red pine	
	Survival	Height	Survival	Height	Survival	Height	Survival	Height	Survival	Height
	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet
1	60	12.1	46	11.6	--	--	59	9.2	--	--
2	41	10.0	36*	7.3	--	--	28	4.3	--	--
3	--	--	84	12.6	84	10.1	90	8.9	61	11.4
4	29	12.6	53	12.8	--	--	63	10.7	36	8.0
5	--	--	--	9.9	77	6.8	--	5.4	--	8.3
6	4	14.4	1	13.8	--	--	23	9.7	21	5.2
			25	9.8						
7	--	--	29	11.4	--	--	--	--	--	--
8	52	21.5	--	--	--	--	29	9.2	--	--
9	80	17.3	32	10.7	--	--	25	9.5	--	--
10	--	--	39	10.7	++	--	--	--	++	--
11	--	--	72	12.5	75	8.4	71	8.2	96	5.7
12	56	17.5	33	12.0	--	--	++	--	++	--
13	30	11.9	4*	1.8	--	--	27	5.5	13	5.9
14	26	15.2	5*	7.1	--	--	15	5.4	--	--
15	72	24.3	56	15.7	--	--	37	11.4	51	5.8
			69	12.1						
16	41	18.4	0*	--	--	--	11	5.8	51	5.4
17	--	--	--	--	--	--	--	8.3	--	--
18	--	--	--	--	--	7.0	--	--	--	--
19	47	20.0	42	12.4	--	--	48	10.0	62	7.5
			53	7.2						
20	33	22.1	5*	5.7	--	--	10	8.0	--	--
21	59	8.7	64	7.8	--	--	47	7.6	--	--
			74	5.4						
22	27	12.5	26	9.5	--	--	28	8.1	--	--

(continued)

Test No.	White pine		European larch		Douglas-fir		White spruce		Ponderosa pine	
	Survival	Height	Survival	Height	Survival	Height	Survival	Height	Survival	Height
	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet
1	62	6.8	--	--	--	--	--	--	--	--
2	49	3.2	--	--	43	2.4	--	--	21	3.0
3	55	5.8	28	6.3	--	--	25	2.8	--	--
4	--	--	--	--	--	--	--	--	--	--
5	--	3.5	22	3.4	--	--	0	--	--	--
6	13	5.9	--	--	3	4.6	--	--	4	3.2
7	38	7.2	--	--	--	--	4	**	--	--
8	--	--	--	--	--	--	--	--	--	--
9	90	7.0	--	--	--	--	--	--	--	--
10	--	--	16	9.9	--	--	++	--	--	--
11	38	3.3	59	7.3	--	--	29	3.5	--	--
12	--	--	--	--	--	--	++	--	19	5.7
13	12	4.0	--	--	--	--	7	2.5	--	--
14	69	4.3	--	--	64	3.6	--	--	34	3.1
15	21	6.9	--	--	49	7.0	60	4.5	24	4.3
16	7	3.7	--	--	45	3.8	47	4.2	--	--
17	--	--	--	--	--	--	--	--	--	--
18	--	--	--	4.3	--	--	--	--	--	--
19	15	3.6	--	--	11	4.1	--	--	8	3.9
20	2	3.1	--	--	0	--	--	--	0	--
21	85	4.8	--	--	--	--	--	--	--	--
22	47	6.1	--	--	--	--	--	--	--	--

*Heavy defoliation by pine sawfly partly responsible for low survival and poor height.

**Cut before 10-year measurement.

++Planting destroyed by re-stripping.

NOTE: On Tests No. 5, 17, and 18, no survival count was made at 10 years because exact boundary of planting could not be relocated. On Test No. 5, 5-year survival for the Banks, pitch, red, and white pines was 13, 19, 41, 18 percent respectively. On Test No. 17, 5-year survival of pitch pine was 54 percent. On Test No. 18, 5-year survival of Scotch pine and European larch was 80 and 30 percent respectively.

Table 7.--Survival and 10-year height, by species, on banks with low, medium, and high soil content

Species	Low soil content (20 - 40%) Basis: 8 banks		Medium soil content (41 - 60%) Basis: 8 banks		High soil content (61 - 80%) Basis: 6 banks	
	Survival	Height	Survival	Height	Survival	Height
	Percent	Feet	Percent	Feet	Percent	Feet
Hybrid poplar	62	31.7	17	28.1	--	--
Black locust	59	23.2	59	25.2	63	23.7
Red oak	53	9.2	52	7.1	91	10.3
Green ash	79	7.6	76	7.5	84	7.9
White ash	73	7.3	70	7.5	82	7.8
Japanese larch	46	16.8	52	17.3	39	12.4
Banks pine*	42	10.6	55	10.0	52	11.6
Scotch pine	75	8.4	75	6.8	80	8.6
Pitch pine	27	6.9	35	8.4	60	9.0
Red pine	74	5.6	42	6.9	48	9.7
White pine	42	4.1	34	5.0	55	6.2
European larch	38	8.6	22	3.4	28	5.3
Douglas-fir	38	2.4	30	5.6	--	--
White spruce	38	3.8	34	3.5	25	2.8
Ponderosa pine	18	3.0	16	4.1	--	--

*Plantings with mortality attributed to pine sawfly are not included. Hence, survival here is higher than overall average survival.

Table 8.--10-year heights, by species, on lower slopes, upper slopes, and ridge-tops

Species	Lower half slope	Upper half slope	Ridge top
	Feet	Feet	Feet
Hybrid poplar	31.2	27.6	34.4
Black locust	23.9	24.3	23.6
Red oak	9.5	7.3	7.8
Green ash	9.8	7.7	6.0
White ash	9.1	6.7	5.4
Japanese larch	14.1	17.5	15.8
Banks pine	11.8	10.1	9.7
Scotch pine	9.6	8.6	8.8
Pitch pine	9.1	8.6	7.5
Red pine	7.9	7.2	7.2
White pine	6.1	5.2	4.4
European larch	10.7	6.3	4.5
Douglas-fir	5.4	5.1	3.3
White spruce	4.5	3.4	3.8
Ponderosa pine	4.2	5.0	3.4


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